Name of Project

Carbon Supplemental Report

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for:
Inyo, Sequoia and Sierra National Forests

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Carbon Supplemental Report

Background

Carbon cycles are an important aspect of terrestrial ecosystem function. Forest plans address some aspects of carbon cycles, in particular related to vegetation and smoke emissions. The amount of carbon in the atmosphere affects global warming. Forests play an essential role in global carbon storage, by removing carbon dioxide from the atmosphere and by storing carbon as biomass within ecosystems. Increases in atmospheric carbon dioxide over the last century have been linked to rising temperatures, and because forests absorb carbon dioxide, they play an important role in regulating climate. In turn, changes in climate, including precipitation and temperature, influence the rates of carbon uptake and loss from an ecosystem. As a result, it has become increasingly important to understand the feedback mechanisms between carbon uptake in forests and climate to ensure the maintenance of healthy and productive ecosystems.

Most of the carbon in ecosystems is stored in plants or in the soil. Trees, shrubs, and organic soils, particularly in meadows are important areas where carbon is stored in the analysis area. When large fires burn, especially when they burn in tree crowns at high intensities, the carbon in live and dead biomass is transferred into smoke, charcoal or "black carbon" and into dead biomass left to slowly emit carbon to the atmosphere and soil through decay. With current vegetation conditions and trends in fires, the amount of carbon stored in forests is unstable and likely to decline. In addition, live trees capture carbon dioxide from the atmosphere, acting as natural "carbon" air filters, while dead trees do not. The trends in increased levels of tree mortality from drought, insects and pathogens and in combination with other stressors, such as air pollution (i.e. ozone) also reduce carbon stability. The proposed plan direction to increase resilience of forests and non-forest vegetation and restore vegetation and reduce the intensity and severity of wildfires are also aimed at restoring carbon storage and cycling stability. Carbon stability is a key characteristic of forests in frequent fire ecosystems (North 2014).

Important Information Evaluated in this Phase

There are several sources of information evaluated for this analysis. One is the strategic plan of the USDA and the 2016 Council of Environmental Quality (CEQ) Guidance. The second is carbon related legislation in California. Finally, there is varied research on carbon sequestration, storage and stability in vegetation in California.

One of the goals of the 2014-2018 USDA Strategic Plan is to ensure national forests and private working lands are conserved, restored, and made resilient to climate change (USDA 2014). The Forest Service roadmap for responding to climate change identifies the assessment and management of carbon stocks as a major element of its plan. Additionally, the 2016 CEQ Guidance provides information to federal departments and agencies on consideration of greenhouse gas emissions and the effects of climate change in National Environmental Policy Act Reviews.

The 2006 Global Warming Solutions Act (CA Assembly Bill AB 32) requires California to reduce greenhouse gas emissions to 1990 levels by 2020, and to identify the most feasible and cost-effective methods to reduce emissions. Reductions may be achieved through a variety of methods, including capping greenhouse emitting sectors (manufacturing, energy production, transportation) and issuing emissions allowances that will achieve these greenhouse gas reductions. Because California forests were identified as a carbon sink, an annual sequestration target of 5.2 teragrams of carbon per year through 2020 was identified for the forest sector. This is to be achieved through sustainable management practices, including reducing the risk of catastrophic wildfire, and the avoidance or mitigation of land use changes that reduce carbon storage. Though non-binding, the plan states that, “The federal government must also use its regulatory authority to, at a minimum maintain current carbon sequestration levels for land under its jurisdiction in California”.

As a result, the Forest Service evaluates current and potential net annual loss or gain in the assessment area’s carbon storage, which determines whether the area is a source or sink for carbon. The feedback mechanisms between carbon storage and long term site productivity in the assessment area are also assessed. Carbon stocks and accounting can be performed in multiple ways. The United States adopted standard accounting and reporting protocols for forests and forest products, adapted from the U.S. Department of Energy 1605(b) methodology -Technical Guidelines for Voluntary Reporting of Greenhouse Gas Program, Chapter 1. These forest carbon estimates included live trees, understory vegetation, standing dead trees, forest floor, down dead wood, soil carbon, harvested wood in use, and landfilled wood products (EPA 2004).

Analysis Assumptions and Methodology

Indicators and Measures

The indicators used to analyze carbon were carbon stocks, sequestration and stability, and emissions.

Carbon Stocks

Carbon stock is a term used here to describe the total pool of carbon in an area, including live and dead biomass, and above and below ground carbon. The analysis here focused on carbon stocks in forests. This is because this is the primary source of losses to the atmosphere in forest fires. Additional information on carbon stored in soil, especially in wet meadows that is released when they dry, was summarized by Long et al. (2014) and in the bioregional and forest assessments (USDA Forest Service 2013-1, 2, 3, 4).

Carbon Sequestration

The term “carbon sequestration” as used here refers to the process of carbon uptake and storage that is carried out primarily by vegetation. This forest vegetation includes carbon estimates for live trees, understory vegetation, standing dead trees, forest floor, down dead wood, soil carbon, harvested wood in use, and landfilled wood products (EPA 2004).

Carbon Stability

In dry forest systems, there can be dramatic changes in carbon stocks and sequestration capacity with one large, high intensity fire. Applicable research on the susceptibility of forests and impacts from large high intensity fires in the Sierra Nevada was recently summarized by North (2014), in the Science Synthesis (Long et al. 2014) and in the bioregional and forest assessments (USDA Forest Service 2013-1, 2, 3, 4)). Carbon stability was a focus of analysis because managing for long-term carbon stability, within a carbon carrying capacity, is a forest-wide desired condition. In addition, carbon stocks and sequestration are both dependent on the carbon carrying capacity, and, consequently, highly related to the carbon stability of an ecosystem. There are several related specialist reports that were drawn upon for this analysis on carbon. This includes: trends in fire with climate in the fire-climate specialist report; trends in vegetation condition and resilience to fire, climate, drought, insects and pathogens in the Vegetation Ecology Specialist Report; and carbon emissions in the Air Quality Specialist Report.

Smoke Emissions and Black Carbon

Fire produces both smoke and charcoal through combustion of live and dead vegetation. Smoke is a carbon source, adding to carbon in the atmosphere while charcoal on or in the soil is considered a carbon sink. The primary source of atmospheric carbon is combustion of vegetation and industrial sources. Vegetation combustion, including prescribed and wildfires managed for resource benefit as part of the proposed treatments may locally increase black carbon deposition. The amount of carbon emissions through combustion and black carbon deposited varies with the: size of the fire, type of fire, vegetation density, location, and prevailing meteorology. Accounting for changes in smoke emissions with restoration of fuels and vegetation condition is complex because prescribed and managed wildfires emit smoke but also reduce the magnitude and duration of potential smoke emissions from large wildfires (Hurteau et al. 2014a, b). Emissions generated under the various alternatives represent a trade-off from higher emissions expected from untreated vegetation by mid-century (Hurteau et al. 2014b). For more detail on smoke emissions from different restoration treatments, wildfires and the tradeoffs between them, see the Fire-Climate supplemental report and the Air Quality section of the draft environmental impact statement.

Analysis and Data

A combination of existing and available vegetation information was used for the analysis. This included forest inventory and analysis plot data and remote sensing, satellite data. Computer models were used to summarize the data into indicators chosen during the assessment phase. Most of the information included in the "Affected Environment" portion was based upon the bioregional and forest assessments. These included information from the WIKI (snapshots), published scientific literature, the scientific synthesis, and the natural range of variation reports.

Carbon Stocks

A nationwide study of estimates of forestland live tree, understory vegetation, standing dead tree, forest floor, down dead wood, and soil carbon stocks was conducted by Heath et al. (2011), using ground-based datasets from the Forest Service forest inventory and analysis program, that summarized data by region and forest. These estimates are broad scale approximations of carbon stocks that did not include harvested wood in use, or landfilled wood products.

Carbon Sequestration

A qualitative analysis of carbon sequestration was conducted based upon scientific literature.

Carbon Stability

Future trends in fire, vegetation stability, and smoke emissions were based on general, documented assumptions because the plan is at the programmatic level and specific locations of restoration treatments are not identified. Quantitative landscape analysis completed by Dr. Westerling and others of University of California Merced on trends in fire area and large fire size was used to base assumptions on trends in fires (Westerling 2015-1). This research included a comparison of 4 levels of landscape restoration. These levels were 15, 30, 60 and 100 percent landscape restoration, focused mostly in the ponderosa and Jeffrey pine, mixed conifer, pinyon-juniper, and sagebrush vegetation types.

The likelihood of large fires, resilience of vegetation to fire, climate, drought, insects and pathogens described in the Agents of Change and Vegetation Ecology Specialist Reports were used to qualitatively analyze the relative differences in consequences amongst alternatives. In general, it was assumed that treatments that reduced vegetation density would positively impact carbon stability. Forest restoration treatments that retain large trees and promote ecological resilience to stressors (e.g., reduction of surface and ladder fuels) are most likely to maximize carbon sequestration and maintain stable carbon stocks over the long term (Hurteau et al. 2014a, North 2014, Krofcheck et al. 2017).

Smoke Emissions

The primary approach was to compare the tradeoffs between potential smoke emissions from the restoration treatments that reduce the potential wildfire emissions and the wildfire emissions that would occur without the restoration. For more detail on the emissions analysis see the Fire-Climate Specialist Report and the Air Quality Specialist Report. Some of the key analysis findings from the fire-climate modeling by University of California Merced (Westerling et al. 2015-1) with varying restoration scenarios are excerpted here to provide a comprehensive analysis in one report.

Assumptions

- It is unknown exactly, when, where or how much wildfire will occur but the trend of increasing large wildfires and associated high smoke emissions (and greenhouse gas emissions, carbon dioxide) will continue.
- Restoration actions that follow the proposed plan and alternatives will result in reduced emissions from wildfires that burn across those areas (e.g. Hurteau and North 2009, North et al. 2009, North and Hurteau 2011, Tarnay and Lutz 2011, Vaillant et al. 2013). Restoration treatments will “offset” future large wildfire emissions. The amount of the reduction depends upon the type and intensity of treatments. See below for a summary of research on forest carbon stocks and sequestration.
- Forest restoration treatments (especially fire restoration) that promote the survivorship and growth of large trees, remove excessively dense small diameter trees, reduce fuel loading, and enhance the resilience of forest stands to stressors are the most effective at sustaining the long-term carbon carrying capacity of fire-adapted Sierra Nevada forests (Hurteau et al. 2014a, North and Hurteau 2011, Krofcheck et al. 2017). These treatments increase carbon sequestration rates over time rather than fluctuating and decreasing suddenly from large, high intensity wildfires that consume live vegetation that no longer is available to sequester carbon.
- Long-term carbon emissions are lowest when vegetation is in a condition that burns within the natural range of variation for a given area. For most vegetation types in the analysis area, this includes burning primarily at low and moderate severity, or crown kill.
- Carbon emissions from meadows increase with drying conditions (Norton et al. 2011, Arnold et al. 2014) and that meadows in good condition store more carbon than in degraded condition (Norton et al. 2006).
- Future projections of carbon emissions and stocks have an inherent degree of uncertainty associated with climate, fire, and vegetation model assumptions. However, some assumptions can be made with high confidence, such as anticipated increases in global anthropogenic carbon emissions and associated increases in temperature (IPCC 2013). By the late 21st century, Sierra Nevada landscapes will largely transition from a carbon sink to a carbon source with reduced carbon sequestration potential, due to the combined effects of climate change and stand-replacing wildfires that increase growing season dryness and tree regeneration failure and decrease tree species richness (Liang et al. 2017a, b).

Analysis Results

Carbon Stocks and Sequestration

Forests Carbon Stocks

Current forest carbon stocks in the planning area are relatively high compared to other forested regions in the United States, with the exception of the Pacific Northwest region (Fried and Zhou 2008, Heath et al. 2011). These greater forest carbon stocks are a result of the relatively higher productivity of Sierra Nevada forests compared to most other regions of the United States. In addition, decades of fire exclusion in many Sierra Nevada coniferous forests have contributed to increased carbon stocks that greatly exceed the natural range of variation (Safford 2013, Meyer 2013-1) and the carbon carrying capacity (Hurteau and Brooks 2011), especially considering warming regional climate (Safford et al. 2012-1) and increasing fire severity trends in the Sierra Nevada (Miller and Safford 2012).

Table 1. Forestland carbon stocks within the assessment area by national forest. Excerpted from the forest assessments (USDA Forest Service 2013-1,2,3)

National Forest	Forest carbon density(Mg C/ha)	Forest area (1000 ha)	Total forest C +/- 95 percent CI as percentage of mean (Tg)	Above ground live tree C density(Mg C/ha)
Inyo	138.9	456	63+/-15	52.6
Sequoia	203.6	393	80+/-17	88.6
Sierra	244.3	455	111+/-14	115.5

Carbon stocks vary widely by the vegetation type. A more detailed assessment of carbon stocks was conducted for the Inyo National Forest based upon research conducted there (Bachelet et al. 2001). The estimates of carbon stocks by vegetation type in the table below is strongly influenced by the proportion in forested lands as opposed to shrublands and meadows.

Table 2. Estimated current carbon stocks on the Inyo National forest by major vegetation type. The table below shows current carbon stocks (g C/m2, 1986-2005). Totals are in units of teragrams (Tg).

Major Vegetation Type	Min	Max	Range	Mean	STD	Area on Inyo NF (acres)	Total
Alpine	4315	15222	10907	11381	2612	129805	5.98
Jeffrey pine	557	12276	11720	7269	2735	135086	3.97
Mountain mahogany	1109	12424	11314	6425	3104	81655	2.12
Pinyon-Juniper	112	12643	12531	2427	3080	561022	5.51
Red fir	683	15719	15036	9899	4134	118039	4.73
Sagebrush	81	15593	15512	3527	4212	308410	4.40
Special type	1243	14145	12902	5582	4354	52784	1.19
Subalpine forest	205	17867	17662	8547	5155	383336	13.26
White fir	736	5711	4975	2307	1581	45671	0.43
Xeric shrublands and blackbrush	89	789	700	248	212	213722	0.21

Carbon Stocks and Sequestration in Other Ecosystems

Other important landscapes contributing to carbon sequestration are shrublands and meadows. Carbon stocks and sequestration have not been quantified in as much detail for non-forested vegetation in most of the analysis area, with the exception of the Inyo National Forest. More than one-quarter of the Inyo National Forest is dominated by shrublands, including sagebrush, xeric shrublands, blackbrush, and mountain mahogany. Less of the Sequoia and Sierra National Forests are in non-forested areas. Meyer (2012) summarized findings regarding carbon storage in cold desert shrublands. The deep rooting systems and high root-to-shoot ratios of these ecosystems results in large carbon reserves, despite the fact that productivity in these areas is low compared to most forested lands, and that their role in the carbon cycle is assumed to be minor. Soil carbon dominates the terrestrial carbon pool, exceeding carbon stocks held in plant biomass nearly five-fold (Janzen 2005).

Similar to shrublands, fens and meadows may play a significant role in the carbon cycle, primarily due to their extensive below ground biomass. Fens are characterized by highly organic soils and are a major sink for atmospheric carbon (Drexler et al. 2015, Weixelman and Cooper 2009). The role of meadows in the carbon cycle is magnified because meadows are typically associated with greater soil moisture compared to surrounding landscapes, and soil moisture is correlated to greater ecosystem productivity and respiration (Norton et al. 2011). The condition of meadows and fens affect their carbon storage and sequestration (Norton et al. 2006). Meadows and fens in poor condition tend to be drier. When meadows dry out, they release carbon because decomposition increases. Meadows and fens in poor condition tend to be drier. See the Aquatic Ecosystem section in the draft environmental impact statement for more detail on meadow condition. Proper functioning condition information for fens indicated that most either were properly functioning, or had an upward trend, or no trend (Weixelman and Cooper 2009). A small proportion was found to have a downward trend. Climate change will result in more meadows drying out and an increase in carbon release to the atmosphere (Drexler et al. 2014).

Soil Carbon Stocks

Soil carbon varies with soil type and vegetation type. In the Inyo National Forest assessment (USDA Forest Service 2013-1) soil carbon was addressed. Based on the Natural Resources Conservation Service soil survey data for this area, soil organic carbon is highest in special types, which includes dry to wet meadows, aspen, and water birch. Subalpine forests and Jeffrey pine also have high soil organic carbon, but it is notable that shrublands such as sagebrush and mountain mahogany exceed some forested types in terms in soil organic carbon. This reflects the higher proportion of below ground to above ground biomass in these ecosystems, as compared to forests. When accounting for the total acreage of each assessment type on the Inyo National Forest, the contribution of non-forest ecosystems, including all shrublands, alpine, and special types, amounts to an estimated 47 percent of the forest soil organic carbon pool.

Carbon Sequestration

Carbon sequestration of vegetation and soils is an important aspect of the carbon cycle in the analysis area, California and broader area. Sequestration is highly dependent upon the amount of live vegetation relative to the amount of combustion from wildfires. The concepts of carbon sequestration and carbon stability are highly related. Below is brief discussion of carbon sequestration and in the following section additional discussion of the relationship between carbon stability and sequestration.

There are some key factors influencing carbon sequestration in the forest. Climate change that affects the growth of vegetation will impact the amount of carbon stored in the forest. Much of the carbon now accumulating in these forests is being added in the form of ladder fuels, which carry fire from the lower vegetation canopy to the upper canopy of trees. As mean fire size and burn severity has increased with vegetation changes, fire has come to play an increasingly important role in carbon storage (Hurteau and North 2009 and 2011, North 2014). Grazing also influences the carbon storage of ecosystems through forage removal, hoof action, and activity that affects soil and livestock waste. Restoration and fuels reduction treatments can reduce forest carbon stores in the short term, but there is a long-term benefit to carbon sequestration and stocks by reductions in fire severity and consequent carbon release (North 2014) including with climate change (Krofcheck et al. 2017). Insect and disease outbreaks can convert forests from carbon sinks to sources (Kurz et al. 2008, Pfeifer et al. 2011). Post-fire management activities that removes snags (i.e., salvage logging) reduces short-term carbon stocks (Powers et al. 2013), but these activities may increase carbon sequestration and carbon storage in the long-term (decades) because: (1) forest carbon sequestered from reforestation activities (with carbon sequestered from the growth and development of planted trees; Peterson et al. 2009, Powers et al. 2013) that follow salvage logging, (2) reduced risk of future uncharacteristic wildfires (such as high-severity "reburns") in areas receiving fuels reduction treatments (Powers et al. 2013, Coppoletta et al. 2016), and (3) carbon stored within wood products rather than lost through decomposition (Johnson et al. 2005). Reforestation activities that manage for resilience are particularly effective at increasing carbon sequestration in fire-prone forest ecosystems of the Sierra Nevada (North et al. 2019). However, there is uncertainty regarding the effects of salvage logging and other post-fire management activities on long-term carbon stocks and sequestration due to a lack of scientific studies addressing this topic regionally and globally (Leverkus et al. 2018). Finally, predicted increases in the population of California will have an influence on carbon storage and sequestration in the assessment area. The primary impact will be through continued carbon emissions and subsequent rising temperatures, which may reduce the long term capacity of terrestrial ecosystems to act as carbon sinks.

Looking at trends in carbon sequestration, a Forest Service study conducted an assessment of carbon sequestration capabilities of the national forests in California over the next 100 years (USDA Forest Service 2009). The Assessment analyzed forest growth, disturbance, and management options under a range of management scenarios for the national forests in California. The analysis concluded that under then current (2009) forest management activities, over the next four to six decades, California's national forests will accumulate carbon at a higher rate than carbon will be lost. This will be at a decreasing rate because of increased carbon loss through disturbances such as wildfire, insect and disease related pest mortality and inter-tree competition. However, at some point in the mid-21st century, carbon losses from wildfire, disease and other disturbances will exceed sequestration, and national forests in California will become net emitters of carbon.

Carbon Stability

Predicted increases in the population of California will have an influence on carbon storage and sequestration in the assessment area. The primary impact will be through continued carbon emissions and subsequent rising temperatures, which may reduce the long term capacity of terrestrial ecosystems to act as carbon sinks. However, forests store and sequester large amounts of carbon (termed carbon stocks and carbon sequestration, respectively) that mitigate anthropogenic greenhouse gas emissions and the impacts of climate change. Factors that affect the growth of vegetation, such as precipitation, stand density, and changes in climate, will impact the amount of carbon stored in the forest.

Much of California's forests have high carbon stocks, reflecting the lack of periodic thinning by natural fires due to a century of fire suppression. This is especially the case in the foothill and montane forests in the analysis area (North 2014). The carbon now accumulating in these forests is being added in the form of dense ladder fuels, rather than in fewer, larger trees across the landscape more characteristic of historic forests. Consequently, stand dynamics such as competition, and stressors such as insects, diseases, drought, and climate change can further reduce carbon stocks (Earles et al. 2014, North 2014). These changes result in reduced forest productivity and increased tree mortality, which in turn leads to increased risk for catastrophic wildfire and further carbon losses (Kurz et al. 2008, North et al. 2009, Hurteau and North 2011, Pfeifer et al. 2011, Stephenson et al. 2014, Wiechmann et al. 2015, McIntyre et al. 2015, Anderegg et al. 2015).

While fire is a natural ecological process in Sierra Nevada forest ecosystems that releases carbon back to the atmosphere, with increasing carbon loss associated with greater fire severity at larger spatial scales (North 2014), as mean fire size and burn severity has increased with vegetation changes in California's forests, fire has come to play an increasingly important role in carbon storage (Hurteau and North 2009 and 2011, North 2014). After high severity wildfire, it is difficult for forests to naturally restore carbon sinks due to decreased survivorship of large trees, the group able to increase carbon stocks the fastest and diminished ability to regenerate effectively, which can lead to longer-term conversions to vegetation types that cannot store as much carbon as healthy forests (Hurteau and North 2011, Carlson et al. 2012, Dore et al. 2012).

Restoration treatments aimed at reducing forest fuel loads and stand densities, such as through thinning or the use of wildland fire, can mitigate the impacts of these stressors and associated carbon loss by restoring the structure and composition of fire-excluded forest ecosystems (Hurteau and Brooks 2011, Hurteau et al. 2014a, Wiechmann et al. 2015). However, these restoration treatments also reduce forest carbon stocks in the short-term through the removal of biomass converted to forest products and prescribed fire-related emissions (North 2014). Consequently, forest management is often challenged with balancing two contrasting objectives: maximizing short-term carbon stocks while maintaining long-term carbon stability. However, it is important to note that while forest carbon may be reduced through treatments, carbon may still remain stored for long-periods of time in harvested wood products. Additionally, shifting forest carbon into harvested wood products may increase the overall sequestration of the forest by freeing up more of the carbon carrying-capacity to take on additional forest carbon while allowing carbon to remain stored in off-site pools (Stewart and Sharma 2015). In the case of carbon emissions from using biomass for energy production, they can displace higher emissions from fossil fuel-based energy production (Stockmann et al. 2014).

Maintaining or restoring forests to fall within the carbon carrying capacity, or carbon stocks that are stored in a functional and resilient ecosystem under prevailing climatic conditions and natural disturbance regimes, would promote this balance and help achieve both short- and long-term carbon management objectives (Hurteau and Brooks 2011, North and Hurteau 2010). Forest restoration treatments that retain large trees and promote ecological resilience to stressors (e.g., reduction of surface and ladder fuels) strongly support these objectives to maximize carbon sequestration and maintain stable carbon stocks over the long term (Hurteau et al. 2014a, North 2014, Krofcheck et al. 2017). This is accomplished by:

1. reducing competition, which allows for higher growth, and therefore, carbon sequestration rates;
2. decreasing mortality, which allows for more carbon to be retained in live and continually growing, rather than in dead and slowly decaying biomass;
3. more large trees on the landscape, which have higher carbon sequestration rates and the ability to store more carbon than small trees; and
4. decreasing loss of forest from catastrophic wildfire (Stephenson et al. 2014, North et al. 2009, Wiechmann et al. 2015).
5. restoring natural fire regimes to Sierra Nevada forest ecosystems, especially under climate change (Krofcheck et al. 2017).

Although short-term carbon losses and slightly lower future carbon stocks can result from management activities, carbon sequestration rates remain increasing over time with more carbon in live pools and less risk of loss to catastrophic wildfire, whereas in unmanaged, fire-suppressed stands, carbon sequestration rates decrease over time as growth rates are stifled from competition, more carbon is transferred from live to dead pools as density-dependent and disturbance-related mortality increases and carbon is emitted through decay, and risk of loss to catastrophic wildfire remains high.

Looking at trends in carbon sequestration, a Forest Service study conducted an assessment of carbon sequestration capabilities of the national forests in California over the next 100 years (USDA Forest Service 2009). The assessment analyzed forest growth, disturbance, and management options under a range of management scenarios for the national forests in California. The analysis concluded that under then current (2009) forest management activities, over the next four to six decades, California's national forests will accumulate carbon at a higher rate than carbon will be lost. This will be at a decreasing rate because of increased carbon loss through disturbances such as wildfire, insect and disease related pest mortality and inter-tree competition. However, at some point in the mid-21st century, carbon losses from wildfire, disease and other disturbances will exceed sequestration, and national forests in California will become net emitters of carbon.

Table 3. Current conditions of carbon measures by major ecological zone/vegetation type. Similarity of current conditions to desired conditions.

Ecological Zone/Vegetation Type	Carbon Stability
Foothill	Low
Montane	low
Upper montane	Low to moderate
Subalpine	moderate
Alpine	moderate
Sagebrush	moderate
Pinyon-juniper	moderate
Eastside pine	low
Desert	moderate
Wetlands (meadows)	moderate

Carbon and Carbon-Related Emissions

This section only displays greenhouse gas emissions under each alternative. Emissions generated under the various alternatives represent a trade-off from higher emissions expected from untreated vegetation by mid-century (Hurteau et al. 2014b, Westerling eta l. 2015-1). To see treatment emissions of other regulated pollutants see the Air Resources section. For more detail on the emissions analysis see the Fire-Climate specialist report and the Air Quality specialist report.

Table 4. Estimate of total carbon emissions for each alternative measured in Gigatons (Gg). Emissions are based on estimates of mechanical and prescribed fire treatment acres provided in Table 4 of the FEIS for the Inyo, Sequoia, and Sierra National Forests. Carbon emissions are based on mechanical and prescribed fire treatment estimates from North et al. (2010), Hurteau and North (2009), North and Hurteau (2011), and Stephens et al. (2009). Carbon emissions estimates that include changes in net biome productivity over time are based on Wiechmann et al. (2015).

	Alternative A	Alternative B	Alternative C	Alternative D
Estimated Carbon Emissions (Gg)	322	566	310	989
Estimated Carbon Emissions with Net Ecosystem Productivity (Gg)	157	261	132	449

Under all restoration scenarios analyzed (Westerling et al. 2015-1, Fire-Climate Supplemental Report), several conditions and trends greatly influence current carbon stocks, sequestration, and especially stability of carbon. First, dense forests will continue to occur across much of the area, because there are no alternatives that restore more than 50 percent of most landscapes (i.e., carbon storage and sequestration will continue in those areas). There may be increases in carbon sequestration in thinned forests, since individual trees will be less stressed and have faster growth. At the same time, under all alternatives, there will continue to be large, high intensity fires, especially in dense forests lacking restoration. When these fires occur, there will be large conversions of carbon stored in forests and soil litter, into carbon dioxide in the air. Climate change will also limit carbon sequestration and stocks following these fires through increased evaporative demand that limits tree growth rates and regeneration (Liang et al. 2017a, b).

The figures below display total carbon (CO_2 and CO) emissions under recent past (“historic” baseline, 1961-1990) conditions and with projected future (2035-2064) changes in climate and wildfires under four different restoration scenarios that approximate the four alternatives: Alternative A (0-15%) treatment, Alternative B (30-60% treatment), Alternative C (15% treatment), and Alternative D (60-100% treatment) (figure 1 and figure 2). These fire-climate scenarios are described in more detail in the Fire-Climate Supplemental Report. For the wildfire-emission scenarios, three coupled fire severity and fuel type scenarios were assessed here following Hurteau et al. (2014). The low wildfire emissions scenario allocates burned areas preferentially to lower carbon-content fuel types and assumes mixed fire severity fuel types ("mixed fuel types") burn at low severity. The central wildfire emission scenario allocates burned areas uniformly across existing vegetation types and assumes mixed fuel types burn at moderate severity. The high wildfire emissions scenario allocates burned area preferentially to high carbon content fuel types and assumes mixed fuel types burn at high severity.

The simulated change in climate by mid-century shows dramatic increases in wildfire and more than a doubling of carbon emissions (Figure 1). Restoration treatments could potentially reduce mid-century carbon emissions to near or below historic levels if implemented across a large fraction of the landscape considered for treatment (i.e., 100% treatment scenario). Additionally, if restoration treatments also result in reduced fire severity by mid-century, the reduction in carbon emissions from wildfire could be greater. For example, failure to reduce fire severity under the 60% restoration scenario can limit carbon emissions to 842-908 Gg, but if treatments are also effective at reducing fire severity and carbon emissions as has been demonstrated in field studies (e.g., North and Hurteau 2011, Carlson et al. 2012, Safford et al. 2012-2), this might further limit carbon emissions to 718 - 842 Gg (close to levels simulated for historic climate at moderate severity) and increase the differences among restoration scenarios. In contrast, if projected changes in climate resulted in higher severity wildfires concentrated in higher carbon content fuel types (e.g., forest ecosystems), then carbon emissions could more than double (i.e., 1701-1835 Gg of carbon loss under the 0% treatment scenario).

This scenario analysis assumes that restoration treatments can be effectively applied at the desired scale, without considering the inherent challenges of treatment planning and implementation. Furthermore, the treatments are implemented in one step and not phased in over time. Finally, this analysis does not account for the carbon removed or released by fuels treatment. However, comparison of restoration treatment carbon emission values presented in Table 4 show that even the greatest carbon emissions associated with high restoration treatment rates (i.e., Alternative D; 449 Gg carbon factoring in vegetation growth and ecosystem productivity) are more than offset by the lower carbon emission benefits in these treated landscapes under projected fire-climate trends (e.g., 859-1039 Gg carbon benefit or difference between the 0% and 60-100% under the moderate wildfire emissions scenario by the mid-21st century; Figure 1). Reduced fire severity and carbon emissions associated with restoration treatments (shifts to lower wildfire emissions scenarios) would further accentuate these differences (see paragraph above). These lower carbon emissions associated with higher rates of restoration treatments are evident in the southern Sierra Nevada ecoregion and larger bioregion (Figure 2). These results are also consistent with recent published studies on forest carbon stocks and emissions in Sierra Nevada forest landscapes (e.g., Hurteau and North 2009, Earles et al. 2014, Hurteau et al. 2014a, Krofcheck et al. 2017).

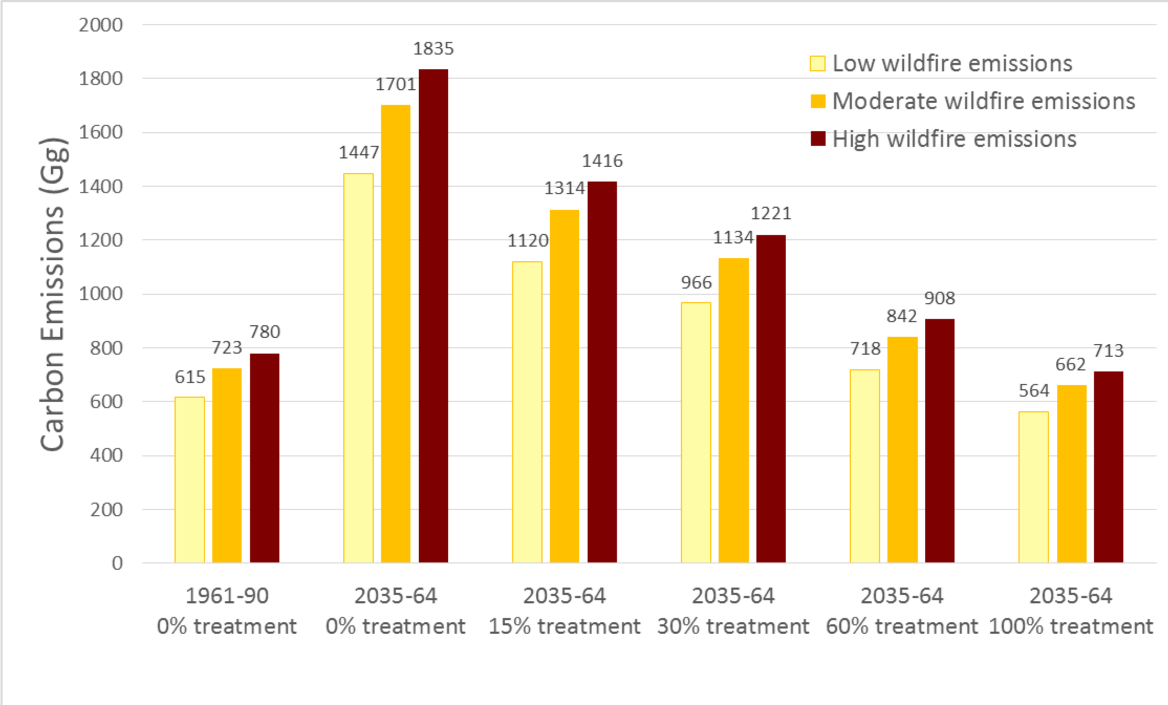

Figure 1. Total carbon emissions (Gigagrams of carbon, Gg on y-axis) for the Sierra Nevada bioregion under five different vegetation restoration and wildfire emission scenarios in the mid-century (2035 to 2064) from the UC Merced study (Westerling et al. 2015). The x-axis represents different time periods (historic baseline conditions for left 3 bars; mid-21st century for all other bars) and restoration treatment scenario (0, 15, 30, 60, and 100%). Values above bars indicate the total carbon emissions under each scenario pair. See Fire-Climate section for more detail on restoration scenarios and modeling. See text for a description of wildfire emission scenarios and representative restoration scenarios for each Alternative.

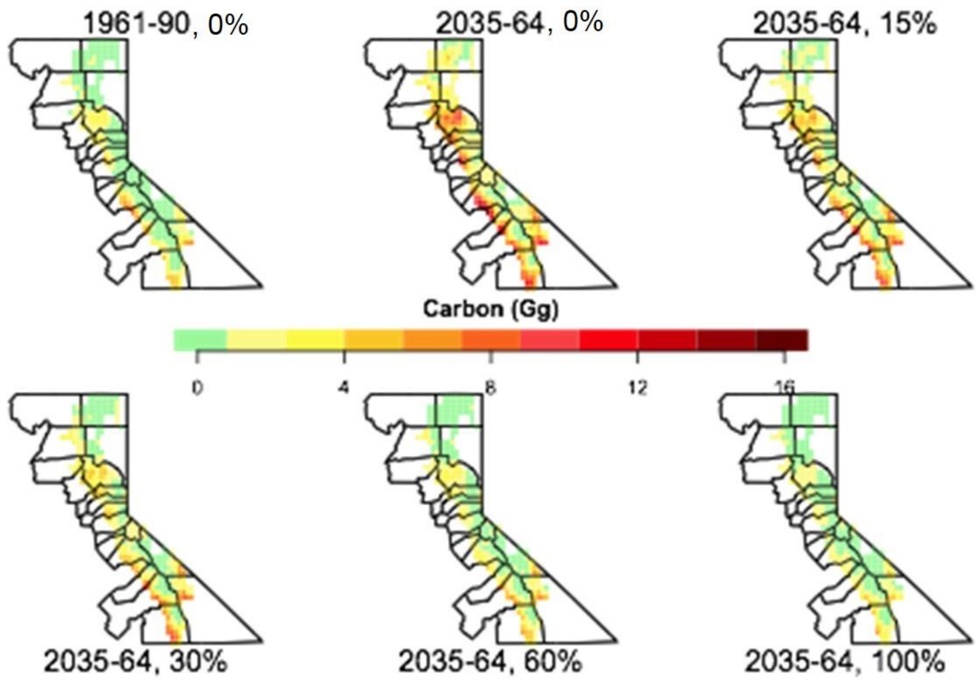

Figure 2. Emissions of carbon (Gg; CO2 and CO) emitted by wildfires for historic climate (1961-1990) and future simulated climate (2035-2064) under five restoration treatment scenarios: 0%, 15%, 30%, 60%, and 100% landscape treatments. These model-derived estimates assume: (1) mixed fuel types burn with moderate severity, and (2) the area burned is allocated uniformly across existing vegetation types in each grid cell.

The graph below (Figure 3) shows cumulative wildfire emissions in the mid-century with different restoration levels. For this analysis, researchers from University of California Merced resampled strategically, to generate some new scenarios. Individual grid cells were ranked from highest to lowest contribution to increased emissions under climate change (highest on the left). The y axis shows the cumulative emissions for all the grid cells included. For the untreated curve, the emissions climb very steeply to the right initially, but then they flatten out as each additional treated grid cell contributes proportionately less to the total cumulative emissions. Similarly for the 15 percent treatment scenario, but with lower emissions throughout since the fuels have been treated in each grid cell. The next three lines show different variations on the admin 100 scenario, where 100 percent of the first 24 percent of grid cells is treated, and 0 percent of the remaining 76 percent of cells is treated. Similarly, if 65 percent of the highest emissions growth grid cells were treated, and none of the remaining cells, and then finally the full 100 percent scenario. The lowest curve shows the full 100 percent treatment scenario, but assuming moderate burn severity in future instead of high severity. Consequently, the assumption about severity has far less impact than the modeled effect of fuels treatments.

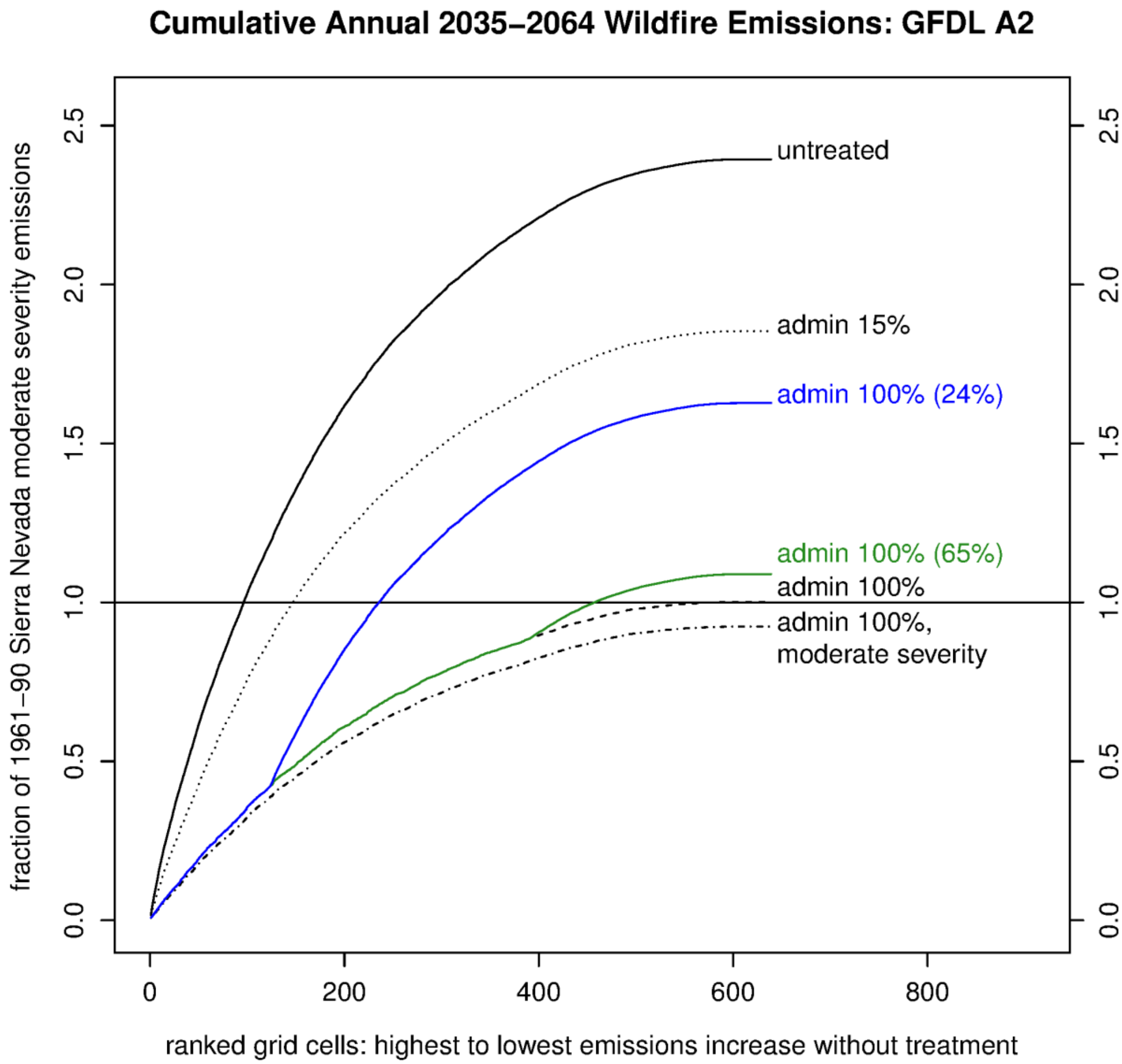

Figure 3. Cumulative Annual 2035-2064 Wildfire Emissions: GFDL A2. Results from UC Merced fire-climate trend modeling. The y-axis shows the fraction of 1961-1990 emissions. The x-axis shows the number of grid cells with increases. The lines represent different restoration scenarios including: untreated (current condition); 15% restored; and 100% restored. There are different assumptions for the severity of fire applied to the 100% restoration including: 24% consumption, 65% consumption, and 100% consumption.

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